Full Paper

EFFECT OF BULK DENSITY ON THE SHEAR STRENGTH OF CLAY-SODIUM SILICATE BONDED MOULDING SAND

S. A. Ibitoye
Department of Materials Science and Engineering
Obafemi Awolowo University, Ile Ife
Osun State, Nigeria
sibitoye@oauife.edu.ng

M. O. Adeoye
Department of Materials Science and Engineering
Obafemi Awolowo University, Ile Ife
Osun State, Nigeria

P. O. Atanda
Department of Materials Science and Engineering
Obafemi Awolowo University, Ile Ife
Osun State, Nigeria

L. E. Umoru
Department of Materials Science and Engineering
Obafemi Awolowo University, Ile Ife
Osun State, Nigeria

G. M. Oyatogun
Department of Materials Science and Engineering
Obafemi Awolowo University, Ile Ife
Osun State, Nigeria

ABSTRACT

This investigation is conducted to establish how changes in bulk density affect the shear strength of moulding sand bonded by clay and sodium silicate. Five sand mixes containing silica sand, sodium silicate gel (1 wt. % to 5 wt. %), potters' clay (2 wt. %), and about 3 wt. % water were produced. Each mix was divided into three portions to which 2 wt. % wood flour, 2 wt. % charcoal and a mixture containing 1 wt % charcoal and 1% wood flour was added to first, second and third portion respectively. In accordance with AFS procedure, each portion was thoroughly mixed and standard cylindrical specimens prepared. Thereafter, bulk densities and shear strength of the prepared standard specimens were measured. It was observed that using any of the three additives, with increasing bulk density the characteristic changes in shear strength assume parabolic form. The sand mix with 8 wt % sodium silicate and 2 wt % charcoal exhibited highest optimum shear strength and castings produced from such sand mix are likely to be less prone to pinhole and scab defect.

Key Words: *binders, bulk density, clay, moulding sand, shear strength*

1. INTRODUCTION

Sand is the principal moulding material in the foundry shop where it is used for all types of castings, irrespective of whether the casting metal is ferrous or non-ferrous. This is because it possesses the properties that are of high significance to foundry purposes. These properties among others include refractoriness which is required to withstand high temperature of molten metal; chemical resistivity needed to avoid any reaction with molten metal; permeability to give access to evolved gaseous products to escape during pouring (Jain, 1979; Khanna and Lal, 1996).

Possession of these properties is only possible if the moulding sand contains in correct proportions, all necessary constituent materials; namely, a refractory based materials such as silica, a binder such as activated clay and special additives such as charcoal, wood flour, dextrin, etc. to impart special properties. Even the best selected sands with all necessary constituent materials in the right proportions may not be able to produce good castings unless efficient and proper preparation and conditioning of the sand are ensured (Khanna and Lal, 1996). Good sand preparation and conditioning ensure that the moulding sands develop optimum properties, sand grains are evenly distributed for adequate binder coating, clay is adequately activated, foreign matter are removed from the moulding sand and sand is delivered for moulding at a proper temperature (Khanna and Lal, 1996; Beeley 2001).

Production of good moulding sand may not necessarily produce sound casting unless good sand moulding is adopted. One of the indices of good sand moulding is the attainment of correct bulk density. Bulk density of sand mould is directly related to some properties of moulding sand such as hardness, green compression strength, green shear strength, green tensile strength and permeability (Khanna and Lal, 1996; Beeley 2001). Low hardness causes low strength which lowers the ability of sand mould to support the weight of flowing molten metal. This leads to metal penetration and sand inclusions in the solidified castings. Excessive hardness gives rise to high strength, which leads to hot tears and cracks in castings due to inability of mould to contract along with the contracting solidifying metal. Low permeability is responsible for formation of gas cavities in casting due to the inability of evolved or trapped air to escape from the mould cavity during pouring (Beeley, 2001; Heine et al., 1967; Rao, 1998). Attainment of correct bulk density during sand mould preparation and conditioning therefore reduces the risk of occurrence of these defects in casting. The influence of changes in bulk density on the shear strength of moulding sand bonded simultaneously by clay and sodium silicate is not yet reported. This is therefore, the object of this study.

2. Experimental Procedure

Dried potters' clay (obtained from Ipetumodu deposit), silica sand (from Osun River Bank), wood flour (fines obtained from saw mill) and powdered charcoal were separately ground and sieved to a fineness of 300 μm. Based on the results of a trial run, five different mixes of silica and potters' clay containing 1% - 5% potters' clay respectively were prepared at increment of 1%. Each of the mixes was divided into three groups. To the first group of each mix, 2 wt% prepared wood flour was added, 2 wt% prepared charcoal to the second group and 2 wt% of a mixture containing equal amount of wood flour and charcoal was added to the third group (Table 1). The choice of these values of wood flour and charcoal was based on the results of a previous work (Ibitoye and Afonja, 1996), which showed that for potters' clay-bonded moulding sand, the moulding properties are optimum when the content of these additives are in the range of 1% to 2.5%.

Table 1: Groupings of various mixes of potter clay, wood flour and charcoal used for the work

GROUP 1	GROUP 2	GROUP 3
1% potter clay + 2% wood flour	1% potter clay + 2% charcoal	1% potter clay + 1% wood flour + 1% charcoal
2% potter clay + 2% wood flour	2% potter clay + 2% charcoal	2% potter clay + 1% wood flour +1% charcoal
3% potter clay + 2% wood flour	3% potter clay + 2% charcoal	3% potter clay + 1% wood flour + 1% charcoal
4% potter clay + 2% wood flour	4% potter clay + 2% charcoal	4% potter clay + 1% wood flour + 1% charcoal
5% potter clay + 2% wood flour	5% potter clay + 2% charcoal	5% potter clay + 1% wood flour + charcoal

Each of the three groups was then sub-divided into five portions and thereafter, 2%, 4%, 6%, 8% and 10% sodium silicate gel (water glass), with density of 1.48 g cm^{-3}, was added to the first, second, third, fourth, and fifth portion respectively. The results of a trial run had shown that reasonable values of the properties under investigation are obtainable when the sodium silicate gel content is in the range of approximately 1% to 10%. Three percent water was added to each of the mixes based on the result of the previous work (Ibitoye and Afonja, 1996) which showed that the optimum properties of potters' clay-bonded moulding sand is obtained when the water content is in the range of 0.5% to 3.0%. Each portion was thoroughly mixed in accordance with American Foundrymen's Society (AFS) Standard procedure (AFS, 1978).

Following the standard procedure (AFS, 1978), 150g of each of the prepared mix were measured into a standard cylindrical specimen tube (5 cm diameter by 5cm high) and compacted using standard rammer. The bulk density of each specimen was determined in accordance with AFS standard procedure. Thereafter, the shear strength of each mix was measured using Universal Strength Tester having passed stream of carbon dioxide through the specimen for about 15 seconds.

3. Results And Discussion

The changes in shear strength with variation in the bulk density when wood flour is used as an additive for different sodium silicate (Na_2SiO_3) contents are presented in Figure 1. The shear strength of the sand mixes gives parabolic characteristics as the bulk density increases (Figure 1). For each mix, the shear strength increases to a maximum value and thereafter starts decreasing as the bulk density increases.

The changes in shear strength with bulk density when charcoal is used as an additive is presented in Figure 2. As observed with wood flour, the shear strength starts to increase to a peak value for a mix of given Na_2SiO_3 content and thereafter starts dropping again. Similar observation is made when the mixture of both additives is used (Figure 3). The optimum shear strength for a given additive used at a given sodium silicate content is presented in Figure 4.

Bulk density of sand mould is directly related to some properties of moulding sand such as hardness, green compression strength, green shear strength, green tensile strength and permeability (Beeley, 2001). Change in the amount of work done during the compaction of the sand is capable of bringing about changes to these properties (Beeley, 2001; Heine et al., 1967). However, having used the standard ramming procedure (AFS, 1978) possible changes in work done during ramming is eliminated. This implies that any variation in the properties of the prepared mixes can only be attributed to changes in the bulk density for any sand mix of given Na_2SiO_3 content (Figures 1 to 3).

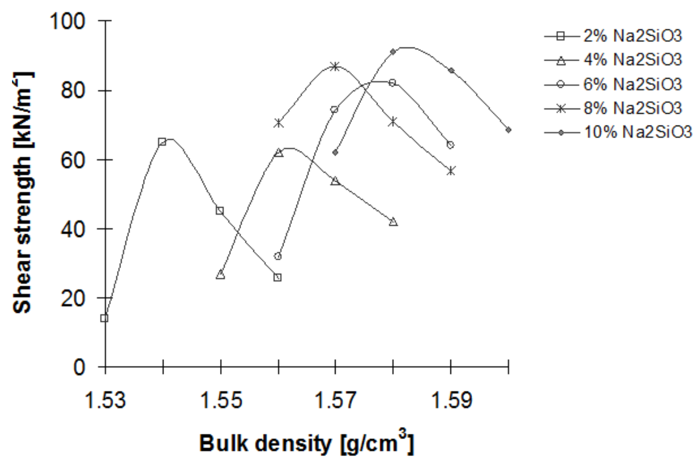

Fig. 1: Shear Strength versus Bulk Density Using 2% Wood Flour as an Additive

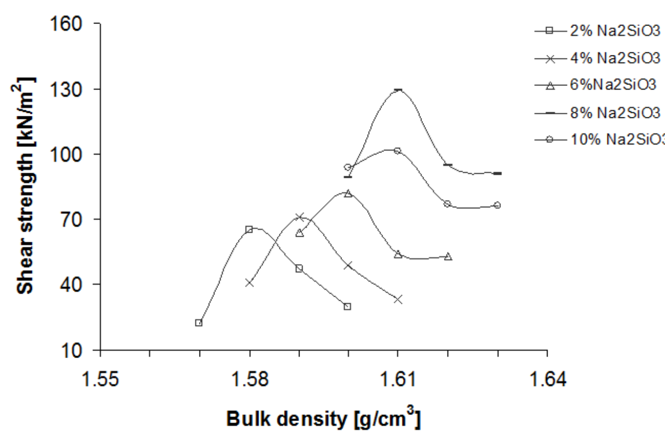

Fig. 2: The Shear Strength versus Bulk Density Using 2% Charcoal as an Additive

For a given mix, the presence of both sodium silicate and clay produces a thin film round the silica particles (Khanna and Lal, 1996; Beeley 2001; Rao, 1998). For sand mix of a given sodium silicate content, as the bulk density increases, particle-to-particle distance decreases due to more sand particles brought closer together within a unit volume (Beeley, 2001; Heine et al., 1967). As the bulk density of the sand changes, the shear strength as mentioned earlier starts changing. The characteristics of the changes for the mixes containing wood flour as an additive assume parabolic form (Figure 1). The reason for the parabolic nature of the changes in the shear strength with increasing bulk density could be explained on the basis of the presence of both the clay and sodium silicate in the mix.

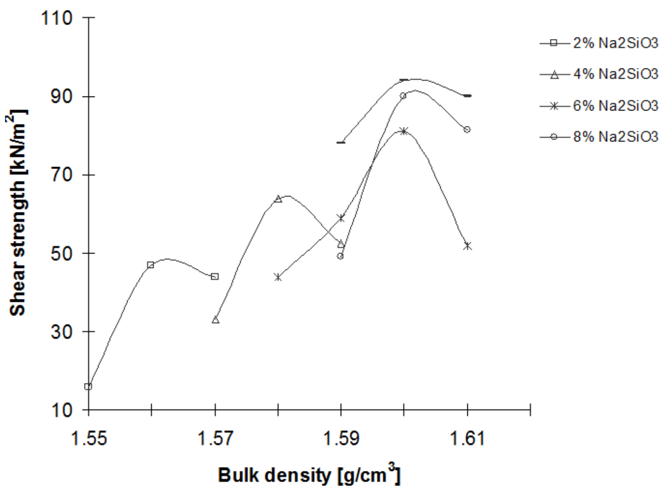

Fig. 3: Shear Strength versus Bulk Density Using Mixture of Wood Flour and Charcoal

Clay is activated in the presence of water (Heine et al., 1967) and when mixed with sand, forms binding coatings round silica sand particles and lens-shaped masses at the points of contact of grains (Khanna and Lal, 1996; Beeley 2001). Sodium silicate (water glass) on the other hand, is a hydrated solution of silicates of sodium. When used as binder in sand mix and in the presence of carbon dioxide, it generates carbonic acid in the aqueous solution. This brings about reduction in pH which causes a rise in the $SiO_2 : Na_2O$ ratio and the formation of a colloidal silica gel. The formed silica gel hardens and forms bond between sand particles which can be summarized by the reaction that follows:

$$Na_2SiO_3 + CO_2 = Na_2CO_3 + \underset{\text{(Silica gel)}}{SiO_2} \qquad (1)$$

In the presence of clay in the mix, silica gel-clay coatings are formed round available silica sand particles. Initially as the bulk density increases, the combined effect of these binders becomes stronger and greater strength is achieved. This probably explains the initial increase in the shear strength (Figure 1). However, with further increase in the bulk density, the distance between neighbouring particles keeps decreasing within a unit volume. A level is then attained whereby the silica gel in the coatings starts having dominant influence. It has been reported that (Hicks, 1971; Liptrot, 1975) the formed and hardened silica gel is porous. Thus, as particles of silica sand get closer due to the increasing bulk density, the amount of clay-sodium silicate gel coatings in a unit volume also increases. It follows therefore that the number of porosity in the coatings within a unit volume also increases and this starts to weaken the bonds between neighbouring sand particles. Consequently, the shear strength starts decreasing after the initial increase for mixes containing 2 wt % wood flour as an additive (Figure 1). This probably is the reason for the observed decrease in the shear strength of the prepared sand mixes containing wood flour as additive after the initial rise thereby producing parabolic characteristics (Figure 1). Similar explanation may be offered for other remaining mixes containing charcoal and the mixture of both the wood flour and charcoal (Figures 2 to 3).

The characteristic change in the shear strength with increase in bulk density for mixes with different sodium silicate contents and 2 wt% charcoal as an additive is similar to what was obtained when wood flour was used (Figure 2). However, for mixes containing more than 4% Na_2SiO_3, the shear strength attained constancy having fallen from maximum to minimum values as bulk densities increase (Figure2). The reason for this behaviour for the group of mixes (some of the mixes containing charcoal) is not very certain but it can be speculated to be associated with some properties of charcoal that is not yet defined. Such defined minimum values and constancy is absent when wood flour or the mixture of wood flour and charcoal is used (Figures 1 and 3).

Except for mixes containing wood flour and 4 wt % sodium silicate, the maximum shear strength exhibited by each mix keeps rising as the sodium silicate content increases in the mix (Figure 4). Comparison of the attainable optimum shear strength for mixes with different additives shows that mixes with charcoal as an additive exhibit highest optimum shear strength. This was exhibited when the sodium silicate content was 8 wt % when shear strength of about 130 kN/m^2 was attained (Figure 4). For mixes containing both wood flour and charcoal, optimum shear strength of about 95 kN/m^2 is attained at 10 wt. % sodium silicate. With 8 wt % sodium silicate, sand mixes containing charcoal are likely to produce castings which are less prone to pinhole and scab (Jain, 1979; Khanna and Lal, 1996) than those with either wood flour or the mixture of wood flour and charcoal. This is due to superior shear strength exhibited at 8 wt % sodium silicate by the mix containing charcoal.

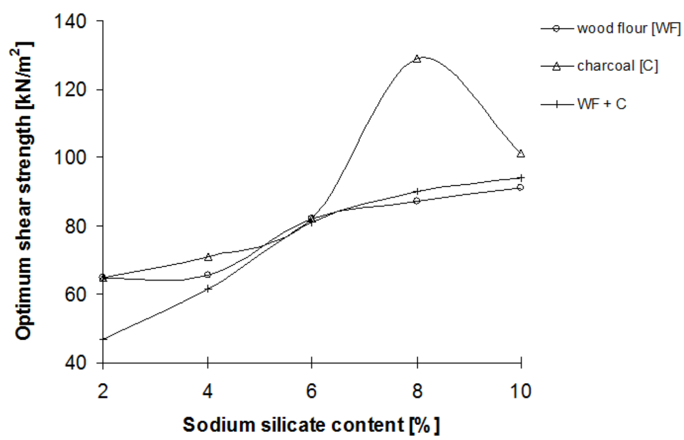

Fig. 4: The Optimum Shear Strength Profile with Sodium Silicate Content

CONCLUSION

The shear strength of clay-sodium silicate bonded sand increases initially as the bulk density increases and thereafter starts decreasing. The initial increase may be attributed to the combined binding effect of the activated clay and silica gel coatings round silica sand particles. The subsequent decrease in the shear strength might be attributed to increase in the number of porosities in the coatings round the silica sand particles within a unit volume. Sand mixes with 8 wt% sodium silicate and 2 wt% charcoal as additive exhibited highest optimum shear strength and castings produced from such sand mixes are likely to be less prone to pinhole and scab defect.

REFERENCES

AFS Foundry Sand Handbook (1978) American Foundry men Soc. (AFS), 7th ed., Des Plaines, Illusionist.

Beeley P. (2001) "Foundry Technology" Butterworth-Heinemann, Oxford, pp 210-211, 454-455

Heine R. W, Loper Jr., C. R. and Rosenthal P. C. (1967) "Principles Of Metal Casting" 2nd ed., McGraw Hill, New York, pp 54 – 58

Hicks J. (1971) "Comprehensive Chemistry" 2ed. MacMillan Press, London, pp 420-421.

Ibitoye, S. A. and Afonja, A. A. (1996) "Determination of Optimum Water Content of Potters' Clay-Bonded Moulding Sand" Ife Journal of Technology 6(1); 25-30.

Jain P. L.(1997) "Principles of Foundry Technology" McGraw-Hill, New Delhi, pp 49-78

Khanna O. P. and Lal M. (1996) "A Text Book of Foundry Technology" Dhanpat Rai, New Delhi, pp 127-132, 486-491, 705-707.

Liptrot G. F. (1975) "Modern Inorganic Chemistry" 2ed., Mills & Boon, Hampshire, p 230.

Rao P. N. (1998) "Manufacturing Technology – Foundry, Forming and Welding" Tata McGraw-Hill, New Delhi, pp 88-104, 194-198.